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SMARTPART: A DATA LOGGING AND RETRIEVAL MICRODEVICE FOR STRUCTURAL AND REPARABLE COMPONENTS

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ABSTRACT

This research seeks to develop a method to electronically log and retrieve data for structural elements or reparable components on aircraft and other defense equipment. The specific research innovation is called the **SmartPart**, which will be designed for real time automatic system tracking of logistics (i.e., supply and maintenance) data for structural and repairable components. The operational design is envisioned as an imbedded or adhesive-mounted, dime-sized device which, when externally activated, would be capable of selective transfer and receipt of data relevant to the component to which it is attached.

In operation, the SmartPart will be capable of providing component identification and other data which will serve as a permanent parts location history. The latter capability will enable the Navy to automatically track the identity of structural and reparable components that are flow on any given aircraft at any time. Since components are interchanged from aircraft to aircraft, the SmartPart will be completely self-contained and maintenance free, requiring no power or external wire connections when the host components are changed.

The anticipated benefits of this research are decreased reparable item maintenance costs, to include the decreased costs of paper- based maintenance documentation. With the SmartPart, there should also be quicker and better responses to updates and/or engineering changes to weapon systems to enhance logistics support to battlefield and/or remote locations.

This report covers the Phase I research on the SmartPart microdevice. Eack key task is covered with a statement of the task, the work accomplished, and the results achieved. In a summary, the SmartPart device was developed in prototype form, however this form was not reduced to a composite printed circuit board and field tests were initialized but not completed as planned.

Nevertheless, we conclude that the SmartPart device is feasible, practical and has significant potential in several areas of defense logistics. Accordingly, a Phase II effort is planned.

TABLE OF CONTENTS

GLOSSARY

TERM	DESCRIPTION
A/D	Analog-to-Digital
ASIC	Application Specific Integrated Circuits
BIT(E)	Built-In-Test (Equipment)
BPS	Bits Per Second
DIP	Dual Inline Package
EEPROM	Electrically Erasable/Programmable Read Only Memory
EMI	Electromagnetic Interference
EMP	Electromagnetic Protection
EPROM	Electrically Programmed Read-Only Memory
FM	Frequency Modulation
FSK	Frequency Shift Keying
KEPROM	Keyed Access Programmable Read Only Memory
Kbyte	Kilobytes (1024 bytes)
LCC	Leaded Chip Carrier
LRU	Line Replaceable Unit
LRM	Line Replaceable Module
LSI	Large Scale Integration
MByte	Megabyte
MOS	Metal Oxide Semiconductor
K/Mhz	Kilo/Megahertz
NVRAM	Non-Volatile Random Access Memory
PC	Personal Computer
PCB	Printed Circuit Board
RAM	Random Access Memory
RF	Radio Frequency
ROM	Read Only Memory
uC(P)	Micro-circuit (processor)
Vcc	Reference Supply Voltage
VHSIC	Very High Speed Integrated Circuits
VLSI	Very Large Scale Integration

- Section 1-
INTRODUCTION AND SUMMARY

1.1 IDENTIFICATION OF THE PROBLEM

Operations, maintenance and support (OM&S) costs constitute over 70% of the life cycle logistics costs of complex, reparable military hardware systems such as aircraft, tanks and ships. Within the OM&S area, the costs of maintenance-related tracking data and information for components and/or structural parts of weapon systems are formidable, and these costs increasing geometrically as the amount data doubles every seven years. There are urgent needs to minimize the costs of providing logistics information in a manner that concurrently enhances military combat readiness.

1.2 SPECIFIC RESEARCH INNOVATION

The objective of this effort is to develop a method to electronically embed selected identification data within or onto structural and/or reparable components, and to selectively retrieve these data on demand. For this purpose, the specific research innovation is a self-contained **SmartPart** which is to be a passive electronic device that serves as the data and information link among hardware and maintenance personnel.

In this research, the SmartPart is to be designed as a stand-alone, software-controlled information logging device to be packaged as a passive VHSIC microchip containing a programmable memory for tracking the life cycle location history of aircraft structural parts. Of specific relevance are those structural and/or high cost reparable parts interchanged among aircraft.

The SmartPart is another follow-on in a sequence of TRACTELL's logistics-related concepts and is based on the TRACTELL-proposed "Logistics Knowledge-base Memory/Template" (LKBMT, DoD SBIR Contract DAAB07-89-C-B801). The LKBMT, as well as the SmartPart designs are applicable to both structural and reparable parts and can be embedded into a host component as a module during manufacture, or adhesively bonded onto the component as a template during retrofit.

In either form, the LKBMT/SmartPart is to be externally powered and is interrogated through a radio-frequency probe. Both devices are designed as a battery-backed, non-volatile, crash-proof memory capable of logistics data retention for ten or more years in a maintenance-free state. As an option, electronic links between the LKBMT/SmartPart and the host could record reliability-related parameters, such as ambient temperature, vibration, humidity, etc., through embedded microsensors, and can also serve as an elapsed time meter.

1.3 BACKGROUND AND STATEMENT OF NEED (SBIR Statement)

> "The requirement exists to develop a real time automatic system for tracking the life cycle location history of aircraft structural parts. Ideally, the structural part should contain an imbedded or adhesive-mounted small (dime-sized) source device which, when externally activated, would emit an identifying signal which would be unique to the host part, and be capable of being permanently recorded.
>
> Since component parts are interchanged from aircraft to aircraft, the source device should be completely self-contained and maintenance free, preferably requiring no power requirements or external wire connections and/or disconnections when the structural parts are changed.
>
> When aircraft power is turned on, it should cause all the source devices peculiar to the aircraft to be activated. These signals should be capable of being recorded concurrently with selected data such as time, date, aircraft serial number, which will serve as a permanent parts location history. The latter capability will enable the Navy to automatically track which structural component parts are flown on any given aircraft. "

As stated in our Phase I proposal, the above-stated specification indicate a conflicting requirement for the operation of the SmartPart device. That is, if the smart device is to be activated when aircraft power is turned on, a requirement must also exist for electrical connectivity of the SmartPart to the electrical circuitry of the aircraft.

Nevertheless, we believe our proposed SmartPart design bypasses this dilemma by allowing data interrogation and transfer on demand through an RF-probe connected to a hand-held computer. The computer, in turn, could be hooked by telemetry to a centralized inventory/repair facility or to a system internal to the aircraft or other defense system. Perhaps in the future, synchronized activation of multiple SmartPart devices could be accomplished through application of newer concepts involving "smart skins" where data and power flow can be effected through the skin of the aircraft.

1.4 ANTICIPATED BENEFITS OF THIS RESEARCH

The goal of this advanced development research is to exploit the new, fast-evolving electronic technologies to electronically embed/retrieve relevant logistics data at the component or structural element level. The result is increasingly greater capability for quicker diagnoses, repair, resupply and component inventory accountability and routing, thereby reducing weapon life cycle costs.

The unique benefits of this research are methods to concurrently enhance the supply and repair sides of military hardware logistics related to inventory control, component routing, and pipeline accountability. The SmartPart will also enhance the automation of embedding and retrieval of selected logistics data and information over disjunctures of time, equipment design changes, and across different hardware items.

- Section 2 -
PHASE I RESEARCH PLAN AND RESULTS AND CONCLUSIONS

2.1 CONCEPTUAL DESIGN OF THE SMARTPART CONCEPT

The Phase I conceptual design of the SmartPart is illustrated in Figure 1. Our approach was to establish the basic operating specifications of this device and select off-the-shelf components for its construction. The prime specifications of the SmartPart are the conditions for data storage and a programmable capability to be effected with external power. Although the operation of the SmartPart will require no internal power through the host component. These general specifications of SmartPart are:

Small, "dime-sized" footprint for component mounting
Passive, maintenance-free electronic data storage
Low operating power consumption - 50 - 100 milliamps
Recovery after interruption of power
Non-volatile storage of data for ten years or more
Secure information storage and access
Built-in calendar clock-timer
Electromagnetic pulse (EMP) immunity;
Electromagnetic interference (EMI) immunity;
Dynamic range for power and data transfer

On the basis of these general specifications, the SmartPart is proposed as an embedded or adhesive-mounted, stand-alone micro- device with radio-frequency (RF) interrogation for a programmable capability using externally-supplied power. In operation, maintenance and/or supply personnel would interrogate and reprogram the SmartPart(s) on demand when a part/component was exchange between aircraft/ship systems, or when a malfunction had occurred, or when an engineering change occurs.

In actual operation, access to the SmartPart circuit is designed to be made with the RF probe which applies power pulses and sends data through a tuned RF circuit. This power charges an internal capacitor which supplies power to the SmartPart's non-volatile memory, recording, measurement, and sensing elements. After power-on activation, the SmartPart will operate in one of two modes: autonomous or semi-autonomous, depending on the extendibility of the current design.

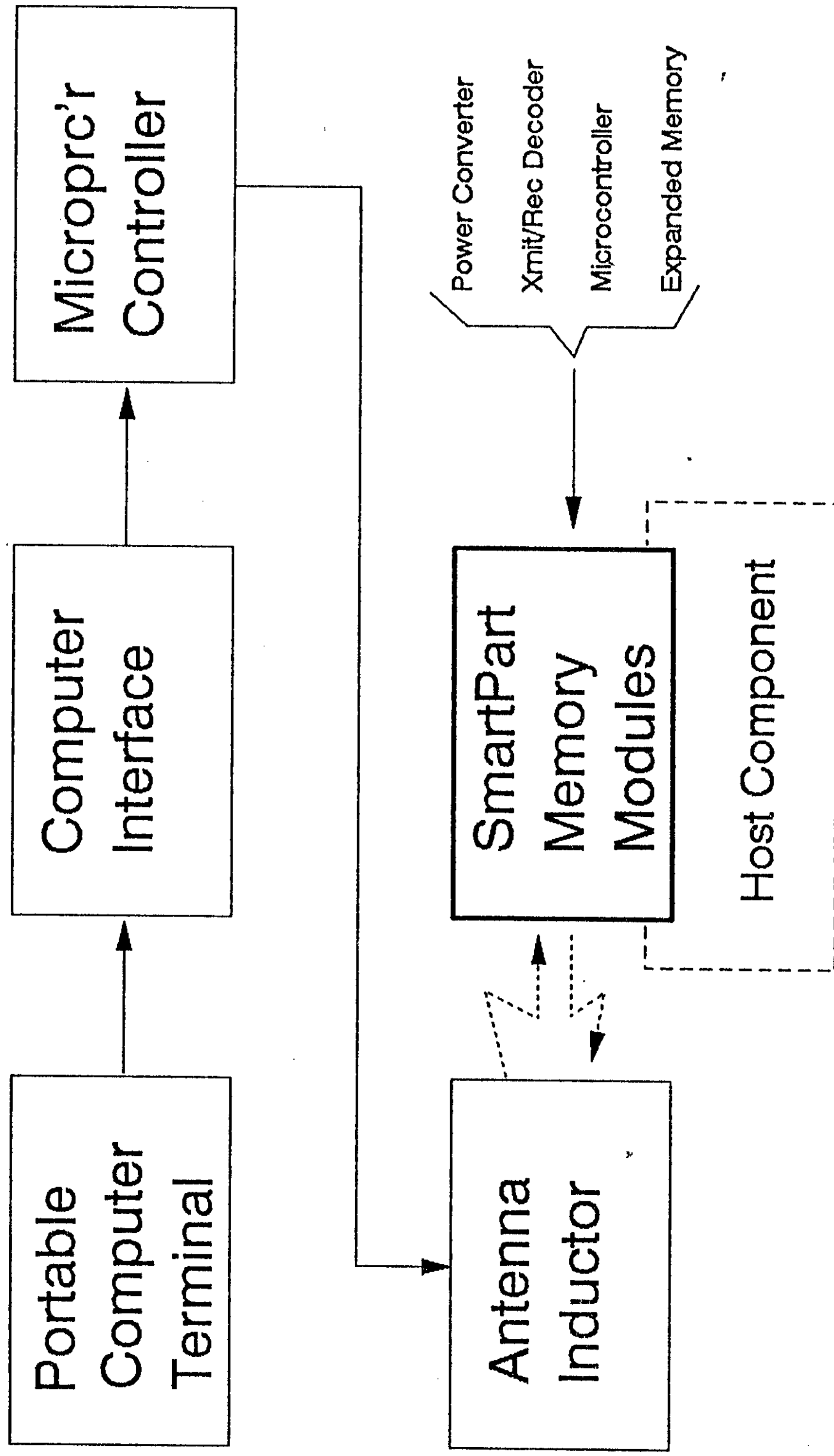


Figure 1: SmartPart Conceptual Design

In the autonomous mode, the RF probe interrogates the contents of the SmartPart memory. Subsequent actions may reprogram or update the SmartPart memory with new data as needed for component initialization on a given system as during component repair, and/or when the host component is interchanged among hardware systems. This programming could be effected as a reparable/structural item was routed into repair and into the pipeline to provide an infinitely more accurate accounting of inventory than is currently available. In the autonomous mode, the power source to the SmartPart circuitry is completely external through the probe.

The semi-autonomous mode goes beyond the design statement of the SmartPart research design in Phase I. In a semi-autonomous mode, electronic linkages from the SmartPart could be made to the built-in-test (BIT) or other sensor circuitry of the host device (if electronically activated). These links could concurrently permit automated time-sequenced storage of part identification and malfunction and/or reliability data to potentially determine when and how as specific element failed. In the semi-autonomous mode, the power to record/sense data by the SmartPart would have to be supplied through the host component circuitry. However, in the absence of power, the SmartPart could revert to its autonomous (passive) operation. Thus, the desired functions of the SmartPart needed to evolve an logistic data recording capability are:

- To retain and accumulate on demand selected logistics information within or on the host component for a time period measured in years;

- To selectively communicate the SmartPart memory states upon interrogation which contain component identification and tracking information.

Based on the Statement of Work (SOW) for this effort, the major research tasks are described below and a summary of the technical approach, work performed and a discussion of the results for each task are cited. Note that Tasks 2, 3, 4 and 5 are actually subtasks under Task 1

2.2 TASK 1: SMARTPART PROTOTYPE DEVELOPMENT

A SmartPart breadboard prototype design shall be developed. The SmartPart shall be controlled and powered by an RF probe. Tests and analyses shall be implemented to establish, debug and refine the SmartPart design. Issues to be addressed include power budget, cross-talk levels, signal attenuation, noise and signal sensitivities, probe positioning tolerances, data/programming time cycles, and ease-of-operation.

2.2.1 Technical Approach for Task 1

The basic design for the SmartPart evolved from a prior TRACTELL project and was refined through the use of automated circuit design methods. The discrete-component elements of SmartPart were hand-fabricated in printed circuit board form. After checks of feasibility and system performance requirements, composite functional devices were purchased that met those requirements.

2.2.2 Work Performed and Results Achieved for Task 1

As a general statement, the work performed on this task are distributed among each of the following subtasks and is described below. Specifically, the SmartPart device was configured in working modules from disparate components and then assembled as a composite device as shown in Figure 2. While all segments of the device worked, the composite device could not be fully tested due to a limitation which was the function of the manufacturer of the key elements of this system. There is little doubt that when the manufacturer resolves the problem we defined, the SmartPart device can be assembled in composite functional form in printed circuit board format.

2.3 TASK 2: SMARTPART PROTOTYPE KEY COMPONENTS

Several commercially available micro-controller integrated circuits shall be examined for prototype application. A study shall be conducted to evaluate selective partitioning and independent powering of the internal functions of the microcontroller integrated circuits. Internal data manipulation and storage, buffering; software requirements and speed shall be factored into this study.

2.3.1 Technical Approach for Task 2

We made an extensive research of the literature to find the most relevant off-the-shelf component fitting the needs of this research. Afterwards, we purchased relevant parts, assembled and tested selected functions in our laboratory, and made changes to the circuit designs to attain the general specifications needed. When the design was reasonably stable, we settled with Dallas Semiconductor as the prime supplier and the design of the SmartPart to be built around the Dallas Semiconductor DS5000T microcontroller to include the DS6068 Wireless Starter kit.

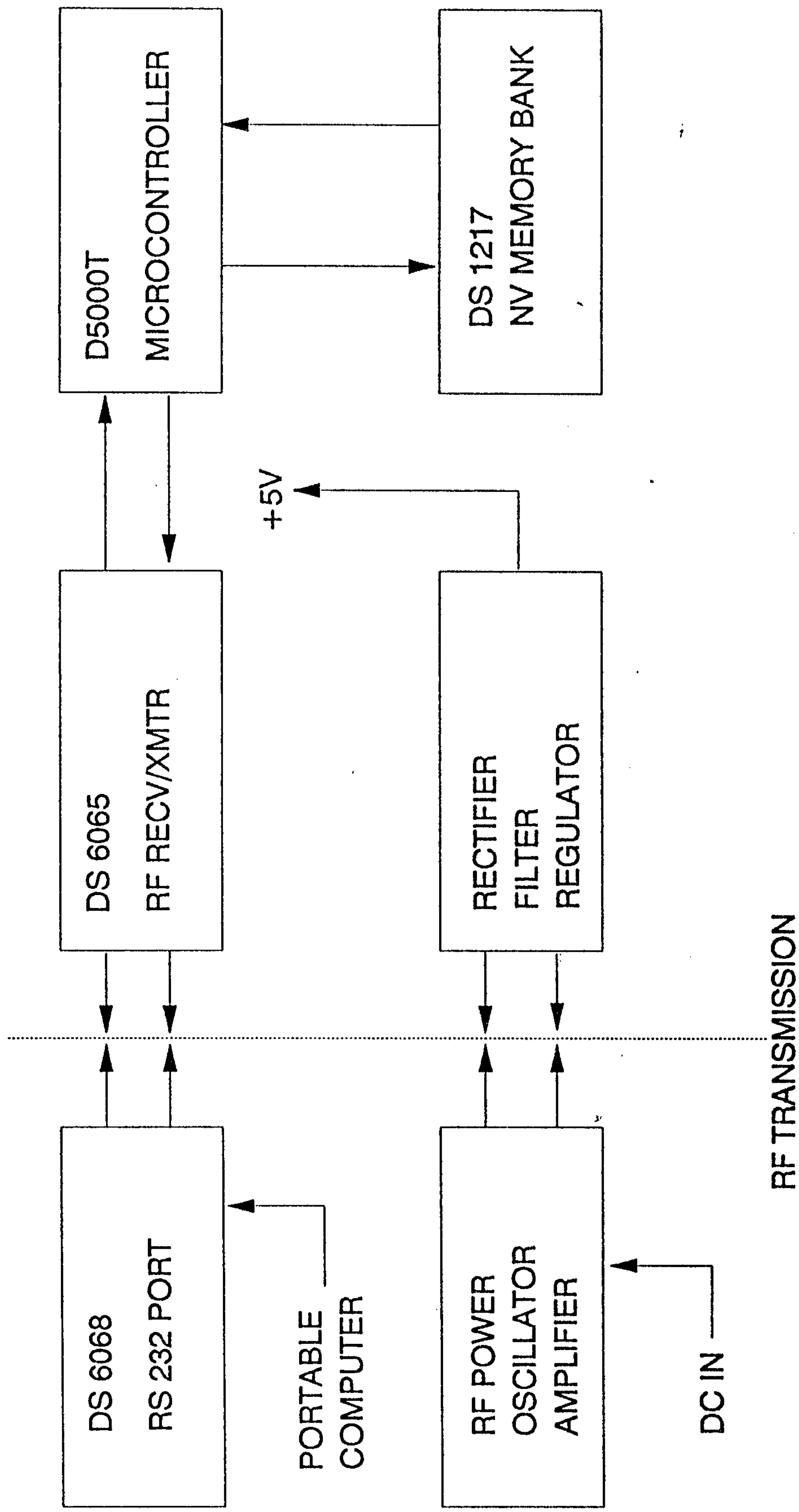


Figure 2: Schematic of SmartPart MicroDevice

The selected parts for the SmartPart prototype were ordered on October 24, 1989. The DS5000T-32-12 microprocessor and associated development kit with documentation and development software were obtained. The DS5000T has a battery-backed, nonvolatile random access memory (RAM) and uses the processor portion of INTEL's 8051 microprocessor. The microprocessor clock crystal was not included in the initial product order and had to be reordered.

2.3.2 Work Performed and Results Achieved

2.3.2.1 Hardware Component Development

Component Acquisition: One of the major problems was obtaining the desired parts through the middle-man operation used by Dallas Semiconductor, which led to extensive delays in this research. However these delays could be considered a tradeoff for having to fabricate similar devices inhouse. Even after acquiring some part, the newness of the devices and proprietary issues meant that no data sheets or other electronic descriptions could be supplied.

Of most significance, the critical units were encrypted with expiration times after which they had to be sent back to the manufacturer for reprogramming. This hidden electronic encryption function was not unknown at the time, and we simply assumed that some error of operation had occurred.

After reprogramming these devices, the units were returned to us but did not work at all. Moreover, the power supply unit apparently was damaged in the shipping but we later fixed this situation. Interacting with Dallas Semiconductor's engineering personnel was helpful, but excruciatingly time-consuming just to get a return call.

Despite all of these setbacks and delays, we were able to configure a basic prototype of the desired SmartPart, to include the add-on module for expanded memory. We simply had to complement our purchased parts with inhouse component fabrications.

Component Refinement and Selective Partitioning: We refined the SmartPart circuit designs and established the electronic specifications of additional compatible hardware components to meet the research objectives. The block diagram in Figure 2 shows the key components of the SmartPart. In our integration of these disparate circuits, circuit layout and designs were effected through the use of the computer-aided- design packages, SmartWorks and HiWire. HiWire contains the capability of autorouting -- which greatly facilitated the inhouse printed circuit development process.

This configuration consisted of the DS5000 development kit module and the DS1217M page addressable memory array in a 256x8bit capacity. This arrangement was primarily made to assist in the development and verification of some of the SmartPart software. While this activity was progressing, it became apparent that a better configuration could be developed using newly-announced the DS6065 "proximity devices or keys" connected to the new DS2250T microprocessor as shown in Figure 3.

In Figure 3, the units representing the core element of the SmartPart are the proximity keys, but these devices have only 256 bits (32 bytes) of memory -- the largest amount currently available for these type of units. Thus, one of our major task was to modify one of these proximity devices to accept an added memory of about 256 kilobytes which was completed and tested successfully.

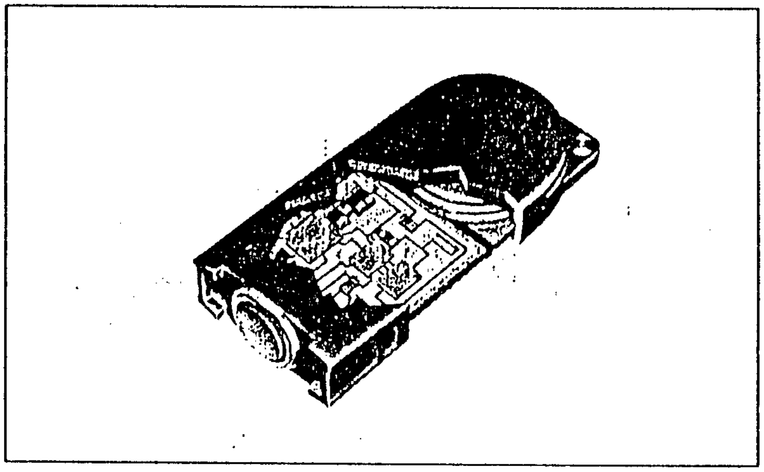
We built the circuit board for interconnecting the DS6065 (the proximity key) to the DS2250 microprocessor using the DS2015 quadport RAM interface from scratch. Using the DS2015 as this interface negated synchronizing the clock of the microprocessor and the proximity key. Since there were no published data sheets, continual interaction with manufacturer was needed to provide the required pin designations and interconnections. Also, we had considerable difficulty obtaining detailed circuit layout and operating descriptions because of propriety issues. Also, the software provided had been developed for a different application using the DS2015 and had to be translated for the specific application of this research.

Moreover, the use of the DS6068K caused several operational problems. This was a beta-demonstration kit that had a conditional use imposed by FCC pending unrestricted approval for a period of about six months. The device supplied to TRACTELL had only 3 months of life before it expired and had to be returned to the manufacturer for reprogramming.

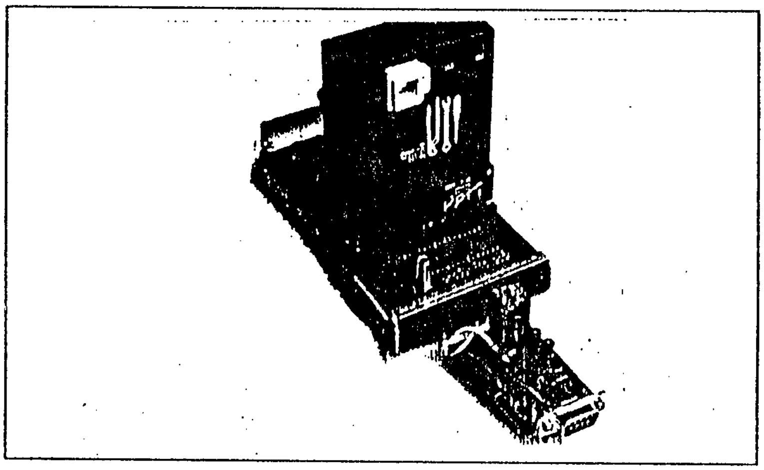
We also adapted and mounted the oscillator crystals for the microprocessor clock circuits. The crystal values of 11.0592 mhz and 1.8432 mhz were chosen to allow the full range of data transfer rates to be exercised to test propagation sensitivities, and the determine power conservation benefits. The crystals have limitations imposed by the FCC on the manufacturer. In addition, the RS-232 interface circuit, a 5-V MC145407D chip was mounted on a circuit board and wired to connect directly to the serial bus of the DS5000. This unit operated successfully.

The DS6068 RF communicator section of the SmartPart design was operated and the unit was able to search and locate all of the three proximity keys used. However, we experienced difficulty in *writing to* the memory of any of the three proximity keys although the identification and security information could be effected in a read/write mode. We are reasonably sure we can operate the devices in a read/write mode for the main memory; this problem appears to be in the device or the software supplied by the manufacturer or both.

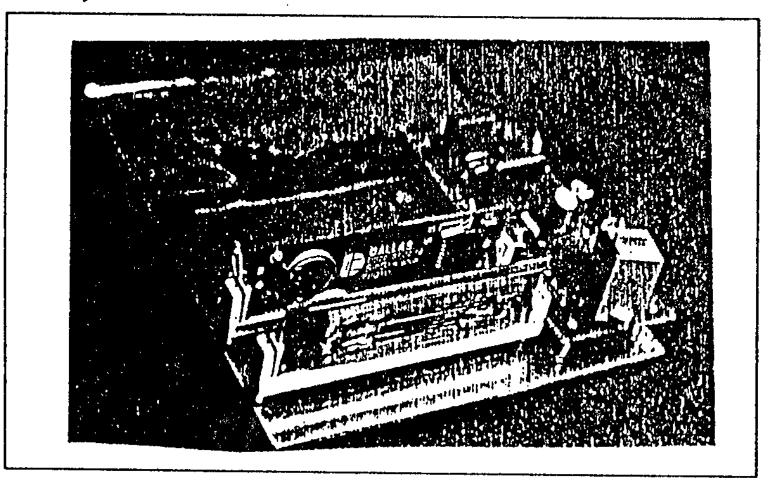
Figure 3: Primary SmartPart Components



DS6065-Proximity Key
SmartPart Core Unit



DS5000
DS1217M Memory Module
RS232 Port Adapter
Software Development Unit



DS6065 Key (Stripped)
DS2250T Microprocessor

We examined the internal wiring schematic of the proximity keys to obtain the data source units to understand the circuit and permit memory expansion in a form of "reverse engineering". The memory module circuit board is contained in a sealed plastic case which required careful slicing to get to the circuit board. After some tedious mapping of the internal circuitry, we were able to wire the DS5000T to connectors and the clock crystal with the expansion port for the expanded memory. In effect, we altered one of the proximity devices to increase the memory from 256 bytes to about 256 kilobytes.

This expanded "data module" was tested using the DS5000-32 microcontroller chip. The chip has 32Kb of battery-backed memory which can be configured as a program and data memory. The chip also has a serial loader to facilitate the software development and downloading of binary code. In the actual operation of SmartPart, this is the memory space that will be designated for component-specific data in a read-write mode.

2.3.2.2 Software Development for SmartPart

SmartPart Software Test Bed: The initial test bed for SmartPart software consisted of the Intel SDK-51 design kit using the Intel 8031 microcontroller chip. The Archimedes C Cross- compiler was used because of its capability to generate ROM-based code, support the Intel Hex Data Format and the ANSI standard for the C language, and the capability of generating the Intel Hex Data format for subsequent download to the Intel SDK-51 Design Kit.

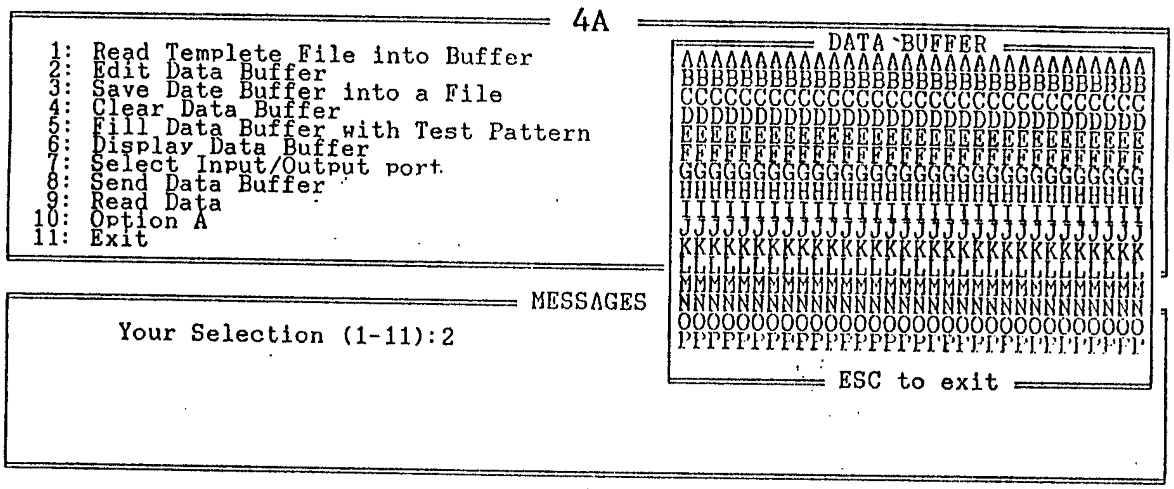
In Phase I, the software tasks concentrated on the development of a communication protocol for data initialization and retrieval system. A new SmartPart proximity key and eventually the expanded memory to be programmed with identification data or the data on the SmartPart can be retrieved, edited and retransmitted back to the SmartPart.

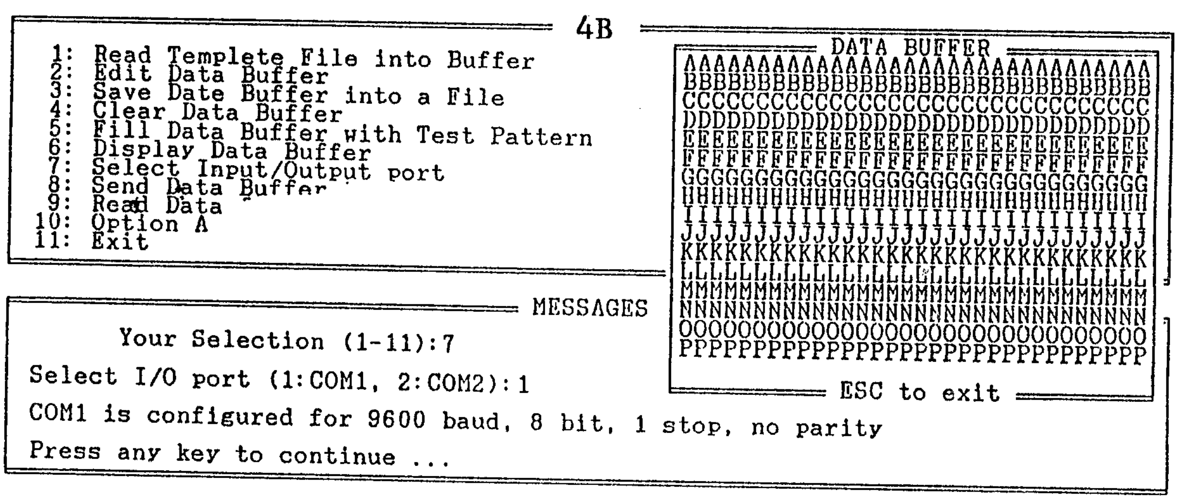
The intended use of the SmartPart device is such that an operator with a portable computer attached to RF probe can initiate a dialog with the device. Thus, all development is performed on an IBM PC compatible computer using the C programming language. As demonstrated in Figure 4A, the SmartPart software is completely menu driven for convenience with ten different operations supported in our test version.

SmartPart Initialization: To initialize each SmartPart proximity device, the identification data must reside in a disk file which can be read. The SmartPart system identifies each key within range of the RF field with a "Find Next Key" command. Each key has a specific identifier and can be addressed independently.

The software allows the operator to read a file from the PC and to store it in a temporary buffer. For the current SmartPart software, the buffer is organized as 16 lines of 32 character

Figure 4: Smartpart Software





each matching the capacity of the SmartPart proximity device of 16x32 characters. The software warns the operator in case of specifying non existing file or an invalid drive as shown in Figure 4B.

In operational situations, we expect that some of the identification data will be fixed while other data will be variable. It is best to think about it as a form where the operator acquires and fills in the particular data pertaining to the host component on hand (e.g. a host component serial number and other logistics data). For this reason, the PC-based software includes a full screen editor where the data in the temporary buffer can be edited and customized for a specific SmartPart device. Option 2 of the software invokes the editor as shown in Figure 4C.

Options are provided to clear the buffer, initialize it or save its data to a disk file (Option 3). If the named destination file already exists, the operator is warned and permission is requested to overwrite the file or to make a different choice. Option 4 is used to clear all the information in the buffer; the data in the buffer will be lost after the use of that option. For test purposes, option 5 is provided where the buffer is filled with a well structured pattern. For example, in Figure 4, the buffer is filled with a fixed test pattern used throughout the Phase I research to permit a quick visual check of the accuracy of the SmartPart data transfer and receipt functions.

To communicate with the SmartPart device, the serial port on the computer is used. The operator can chose between using COM1 or COM2 for that operation. Option 7 is used to determine which port is to utilized. Once a determination is made, the port is configured for 9600 baud, 8 bit, 1stop, and no parity as demonstrated in Figure 4D.

If the operator of the SmartPart system attempts to send or retrieve data from the SmartPart proximity device before assigning one of the serial ports, a warning message is displayed as in Figure 4E. The purpose is to assist the operator to successfully complete the desired operation with minimal effort.

To send data to the SmartPart device, option 8 is used. The data in the temporary buffer is transmitted over the selected serial line to the SmartPart. Secure communication is achieved by hand shaking procedure as explained below. The system indicates the transmission status as shown in Figure 4F.

To retrieve data from a SmartPart device, option 9 (Read Data) is used. The received data from the proximity device is collected in the temporary buffer where it can be edited or saved in a disk file. Figure 4F demonstrates the operation of this option where the system acknowledges the reception of one line by printing a dot stream on the screen.

Option 10 is reserved for system software development. Basically, it opens a new window where the SmartPart software can be upgraded, a new password is installed, a new configuration for the micro-controller is established, .. etc. This is the programmable capacity needed

Figure 4, Continued

```
══════════════════════════ 4C ══════════════════════════
 1: Read Templete File into Buffer
 2: Edit Data Buffer
 3: Save Date Buffer into a File
 4: Clear Data Buffer
 5: Fill Data Buffer with Test Pattern
 6: Display Data Buffer
 7: Select Input/Output port
 8: Send Data Buffer
 9: Read Data
10: Option A
11: Exit

═══════════════════════ MESSAGES ═══════════════════════
     Your Selection (1-11):
```

```
══════════════════════════ 4D ══════════════════════════
 1: Read Templete File into Buffer
 2: Edit Data Buffer
 3: Save Date Buffer into a File
 4: Clear Data Buffer
 5: Fill Data Buffer with Test Pattern
 6: Display Data Buffer
 7: Select Input/Output port
 8: Send Data Buffer
 9: Read Data
10: Option A
11: Exit

═══════════════════════ MESSAGES ═══════════════════════
     Your Selection (1-11):1
Enter Templete Filename:abc.tmp
Templete file: abc.tmp does not exist
Press any key to continue ...
```

Figure 4, Continued

4E

```
 1: Read Template File into Buffer
 2: Edit Data Buffer
 3: Save Date Buffer into a File
 4: Clear Data Buffer
 5: Fill Data Buffer with Test Pattern
 6: Display Data Buffer
 7: Select Input/Output port
 8: Send Data Buffer
 9: Read Data
10: Option A
11: Exit
```

MESSAGES

```
     Your Selection (1-11):8
An I/O port must be selected first
Press and key to continue ...
```

4F

```
 1: Read Template File into Buffer
 2: Edit Data Buffer
 3: Save Date Buffer into a File
 4: Clear Data Buffer
 5: Fill Data Buffer with Test Pattern
 6: Display Data Buffer
 7: Select Input/Output port
 8: Send Data Buffer
 9: Read Data
10: Option A
11: Exit
```

DATA BUFFER

```
AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA
BBBBBBBBBBBBBBBBBBBBBBBBBBBBBBBB
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
DDDDDDDDDDDDDDDDDDDDDDDDDDDDDDDD
EEEEEEEEEEEEEEEEEEEEEEEEEEEEEEEE
FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF
GGGGGGGGGGGGGGGGGGGGGGGGGGGGGGGG
HHHHHHHHHHHHHHHHHHHHHHHHHHHHHHHH
IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII
JJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJJ
KKKKKKKKKKKKKKKKKKKKKKKKKKKKKKKK
LLLLLLLLLLLLLLLLLLLLLLLLLLLLLLLL
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM
NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN
OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOO
PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP
```

MESSAGES

```
     Your Selection (1-11):8
Sending data ...............
```

to reinitialize or reset the device if, for example, the host component has been overhauled or reconditioned.

SmartPart Security Communication Protocol: Communication between the Smart-Part and the interface system (the handheld PC) is performed in an encoded form for security and error detection purposes. Framing characters (%, $ and #) are used to facilitate the detection of framing errors and to request correction. Handshaking is implemented using acknowledge-no- acknowledge-retransmit ($C, $N and $R respectively) commands. Figure 5 describes the communication establishing method and the different commands necessary to interrogate the SmartPart device. Repeated commands are not shown in Figure 5.

We anticipate that in the next phase of this research, a more sophisticated security system will be used. The capability of data encryption offered by the DS5000 module will be utilized to further enhance the security aspect and the implementation of crash proof system. The disadvantage of slower system performance due to encryption/decryption is offset by the enhancement of data security.

It is to be noted that the transmission difficulties between the computer and the proximity keys prevented a full exercise of the developed software. We feel certain, however, that pending the return of the functioning devices from the manufacture, this software will work as planned. Also, in the follow-on stages of this research, considerations for using the programming language ADA has already been made due to the generic requirements for this language in all embedded systems.

2.4 TASK 3: PROBE-TO-SMARTPART POWER TRANSFER

The RF probe shall be optimized with respect to power budget, frequencies and modulations. Trade-offs shall be established with respect to component size, ease of fabrication and cost. Alternative candidates for an RF link shall also be identified and evaluated. Acoustic, inductive and optic alternatives shall be considered.

2.4.1 Technical Approach for Task 3

Due to the selection of off-the-shelf, vendor-dependent parts for the SmartPart prototype, we used an omnidirectional antenna shown in Figure 6 in place of a more directional RF probe to interface with the portable computer that formats and interpret the data from the SmartPart devices. This was done for expediency and the matching of the components from the same manufacturer. However, during the research, we initiated methods to downsize the antenna to probe-like dimensions as explained under Task 4.

Figure 5: SMARTPART COMMUNICATION SECURITY PROTOCOL

```
------------|-------------|-------------------------------------
OPERATION   |     PC      |          SmartPart Response
------------|-------------|-------------------------------------

signal            %S    -->     Wake up and restart
                          |<--  $P  acknowledge, get password
                          |<--  $R or, repeat please
                          |
password     SmartPart -->|
                          |<--  $C    Okay,  valid password
                          |<--  $N   or, invalid password
                          |
read data         %R    -->|
                          |<--   line 1
                          |.
                          |.
                          |<--   line 16
                          |<--  $C    Okay,  valid reception
                          |<--  $N   or, invalid password
                          |
write data        %W    -->|
                 line 1 -->|
                    .      |
                    .      |
                line 16 -->|
                          |<--  $C    Okay,   valid reception
                          |<--  $N   or, invalid password
                          |
quit                %Q  -->|
                          |<--  $X
                          |<--  $R or $N
------------------------------------------------------------------
```

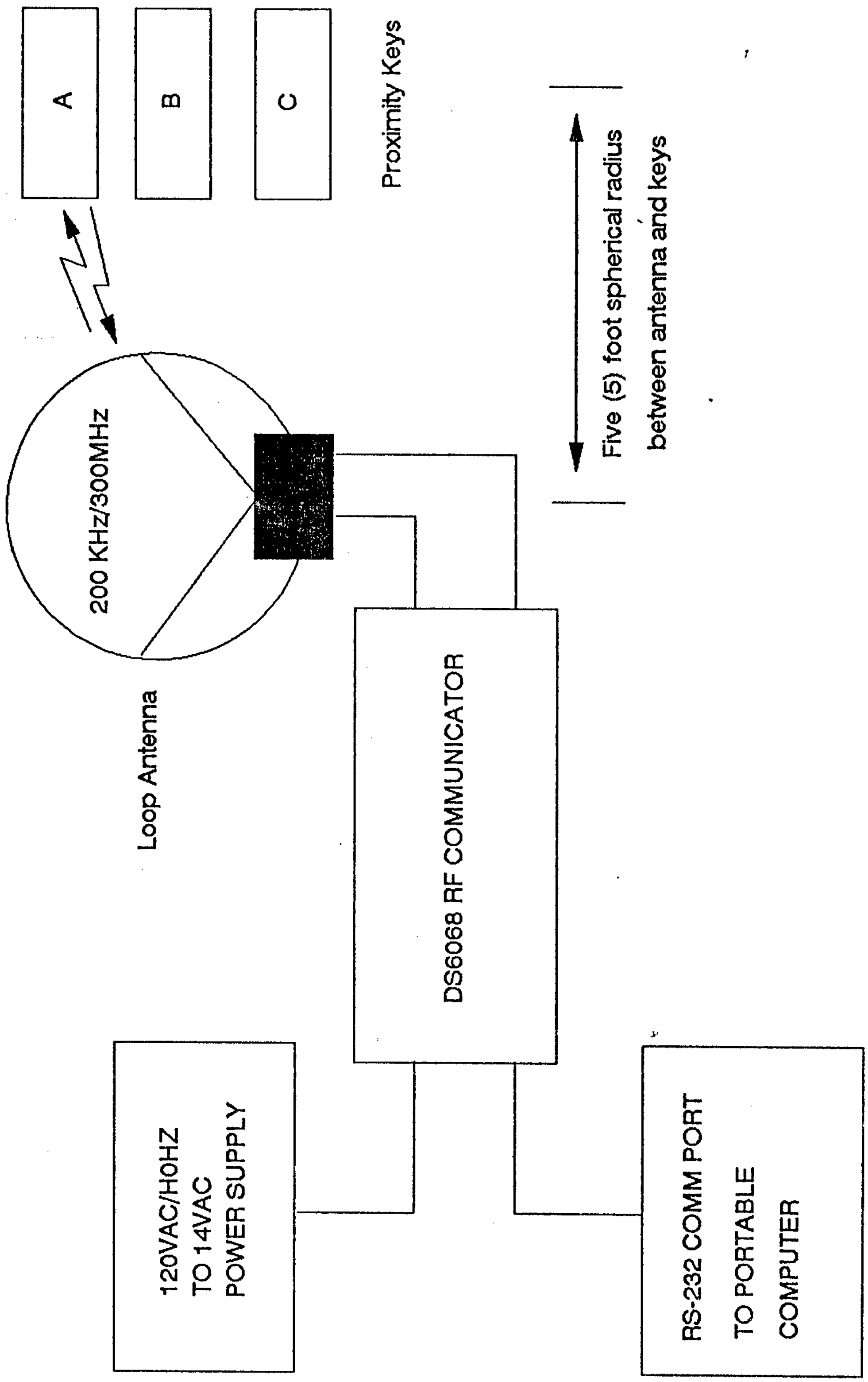


Figure 6: The SmartPart Antenna Configuration

2.4.2 Work Done and Results Achieved for Task 3

The antenna configuration shown in Figure 6 is rather large 15-inch diameter loop designed to operate at a 200khz transmission frequency with a 300 mhz dipole shaped in a "Y" configuration and tied within the loop. This antenna was used in place of the specified RF probe during Phase I. Although the current design is bulky, it was effective at demonstrating the feasibility of the SmartPart design. Thus, in Phase I, we focused only on the antenna which seem quite effective at locating and communicating with all proximity keys within a five (5) foot spherical radius with no intervening impediments.

As a concurrent event, we initiated an effort to scale this antenna down in a size that would more resemble a probe since the original design was intended for a separation distance between the RF exciter and the memory unity. A much closer proximity than five feet is intended for the **SmartPart** because of the RF power transfer requirements (which is the main reason we did not test the antenna transmission and reception through likely physical impediments).

In this modification effort, we obtained a split ferrite core with a cross-section (See Figure 7) of about 1.25 inches to construct a model of an antenna-inductor that would load the RF transmitter as much as the large RF loop antenna did. It would also determine whether the required voltage ratio transformation could be achieved to provide the SmartPart with the 8 to 9 volts needed before rectification, filtering and regulation to produce the 5 volts at 50 to 100 milliamps. Although this progress was positive, we postponed this effort for higher priorities, however this effort will commence again in deference to Task 4 described below.

2.5 TASK 4: SMARTPART PROTOTYPE OPERATIONAL CONSIDERATIONS

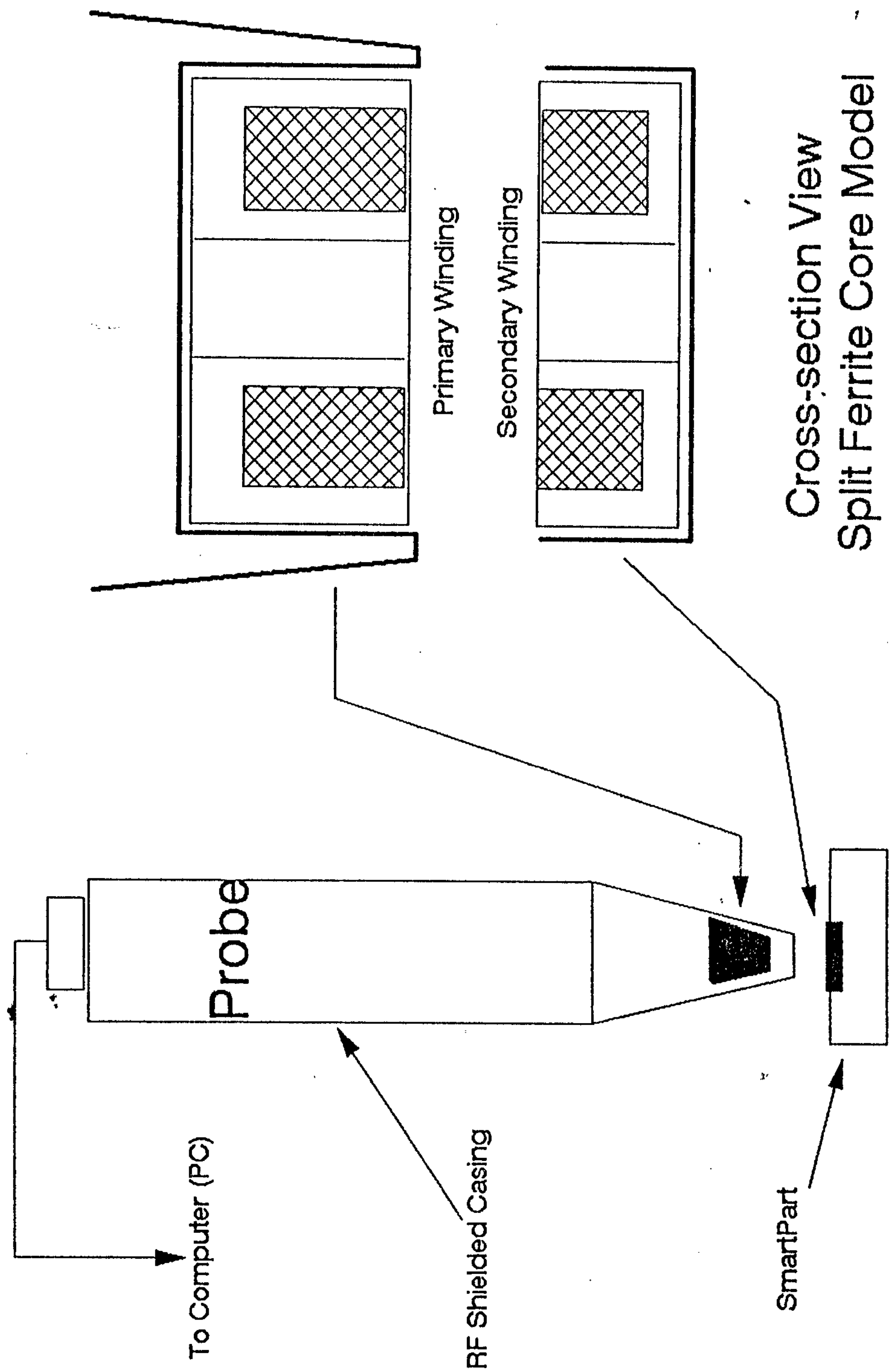
Tests shall be performed to assess mutual interference among the SmartPart prototype, probe and other elements of the system to determine if shielding is necessary. The effects of shielding on the design shall be factored into, and addressed in all research tasks.

2.5.1 Technical Approach for Task 4

RF emission levels are controlled by containment of the radiating element within metal enclosures to house the RF generating and radiating aperture for SmartPart.

In its initial design form, the SmartPart probe is intended to be cylindrical in shape and have the radiating and receiving elements in one end within coaxial cavities. A shallow matching

Figure 7: RF Probe and Shielding Configuration



configuration would exist on the SmartPart's proximity key. The physical volume occupied by these probe elements would primarily depend on the amount of power transfer needed. Other considerations such as capacitor size and electrical activity on the SmartPart would moderate the power needed.

When the probe and SmartPart are brought in close proximity, less RF energy gets scattered to interfere with external devices. If surface contact is made, leakage should be negligible. In the latter case, a contact microswitch could be used to allow RF power to be emitted on demand.

We envision the completed SmartPart probe to consist of the split pot core transformer configuration as shown in Figure 7 for relatively low frequency (200KHz or 133Khz) aperture that should inherently yield a low external radiating field. Partial encasement in the metallic cylinder of the probe would further reduce emissions.

In this preliminary design, internal circuitry in either the probe or SmartPart module would be isolated by metallic baffles, encasement recesses or skeletal partitions. Very likely, the microprocessor may have to be isolated from the transceiver in the SmartPart device.

2.5.2 Work Performed and Results Achieved for Task 4

The 1.2-inch diameter ferrite pot core assembly (Figure 7) was acquired with the intent to fabricate a split core transformer as a first-cut configuration for the RF probe and to use this configuration for measurements with the network/spectrum analyzer. The parameters obtained were to be used to estimate the extent an operational probe could be reduced in size for the SmartPart system assembly and the mechanical consideration for shielding and operation were to be determined.

However, this work was deferred because of the extensiveness of other tasks, particularly the work with the DS6065K components, and the extensive delays in the acquisition of required component parts.

2.6 TASK 5: SMARTPART PROTOTYPE PACKAGING

The design shall be reduced to a printed circuit board (PCB). Packaging studies of the SmartPart shall include functional/laboratory testing, field testing and operational use issues.

2.6.1 Technical Approach for Task 5

Our objective was to acquire off-the-shelf components, test and marry their capabilities as disparate units, and then merge these components to a printed circuit board.

2.6.2 Work Performed and Results Achieved for Task 5

We assembled the last prototype packing for the SmartPart as shown in Figure 8 which consists of the DS5000(T), the DS1217M Bank Switched memory expansion to 256K bytes, a removable RS231 port, and a 5 volt regulator. We used the DS2015 Quad Port RAM to couple a DS6065 proximity key to the DS2250 microprocessor. The port and the regulator are independently detachable. When the regulator is detached, the RF power transfer circuit will be used. The port simply permits computer software operations: this port will not be part of the end product SmartPart.

The assembly shown in Figure 8 consists of a later, more compact microprocessor package designated the DS2250T with 64K bytes of non-volatile memory, and a new exposed proximity key (DS2267A) modified to allow it to be externally powered; this is ideal for the follow-on SmartPart design. This version of the key receives at an FCC-approved 133khz and replies at 303.95mhz.

We anticipate the full PCB layout in the form shown in Figure 8 and we expect that the physical dimensions of this layout will shrink by a significant factor due to the known compaction of several of the discrete devices.

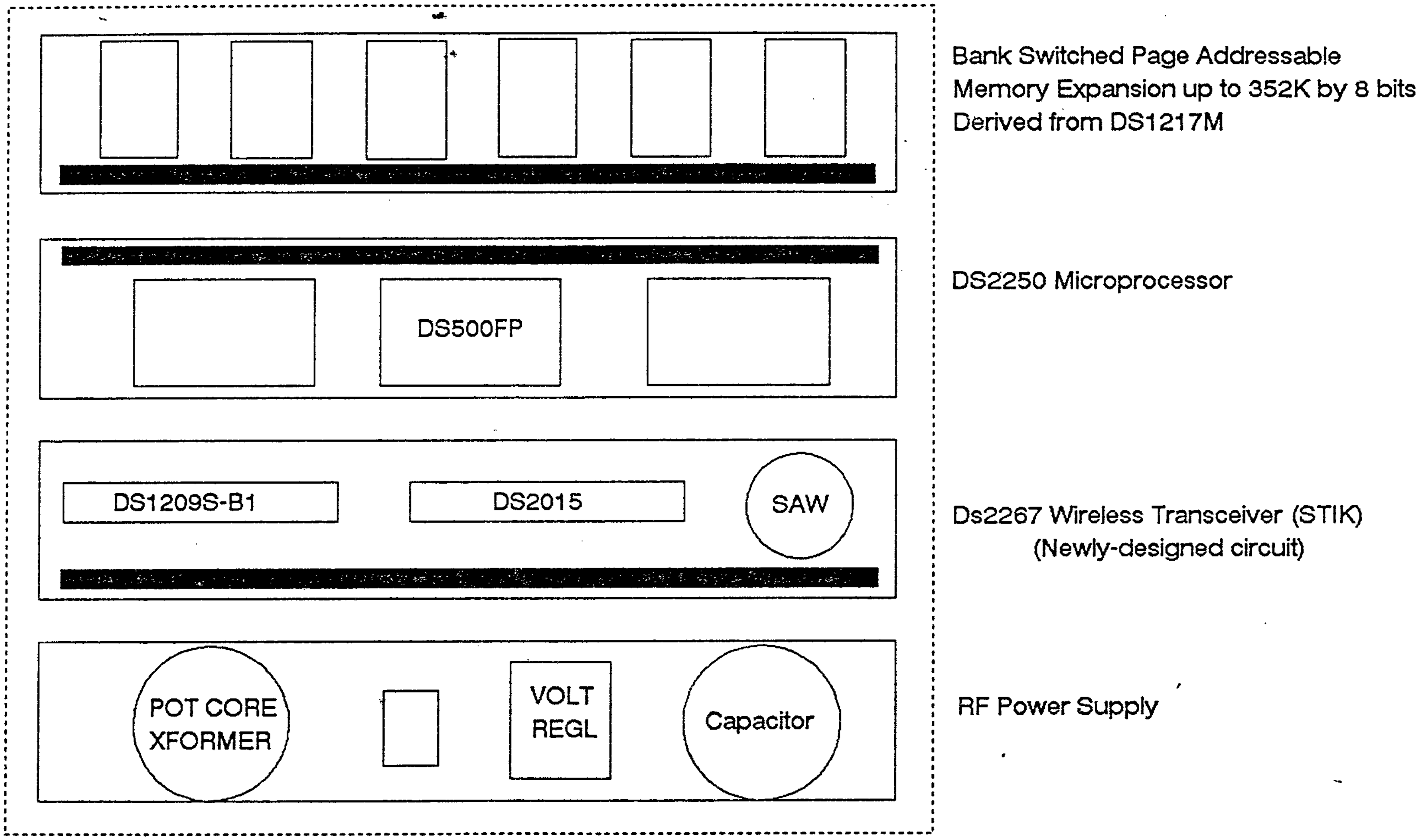
2.7 TASK 6: SMARTPART PROTOTYPE FIELD TESTING

A SmartPart prototype in PCB form shall be tested on a real part of the contractor's choice. Prototype operational and functional tests shall be conducted during the field test. The effects of temperature, moisture, vibration and stress shall be examined.

2.7.1 Technical Approach

In Phase 1, the composite SmartPart prototype was not tested on a real part due to time limitations. However, we performed extensive testing of individual elements of this device in such a way that we gained much insight into the working of an operational SmartPart.

Figure 8: SmartPart Configuration For PCB Packaging



Packaged Dimensions: 2.5x2.0 inches (Not to Scale)

2.7.2 Work Performed and Results Achieved for Task 6

We used our HP 4195A Network/Spectrum Analyzer to make impedance measurements of the DS6068K antenna loop with the intent to fabricate an equivalent device of smaller dimensions similar to an RF probe (Figure 7). We deferred this activity when we learned of the new FCC approved operating frequency of 133mhz for the next revision of this antenna which will permit the desired transfer of power and data.

We made tests on the high level 200khz output spectrum of the DS6068K to determine it's emission characteristics and to diagnose a suspected intermittent operation in the antenna loop. Apparently the leads in the crimped metal sleeve had loosened during transport or handling. This problem was resolved by resoldering the connections.

Using the HP4195A analyzer, we attempted to monitor the 300mhz frequency reply from the DS6065 key (to which the DS6068 transmitter communicates) to see if we could determine why we were having trouble in this link. This probing required the addition of a preamp circuit to be added to the analyzer loop. During these tests, the internal timer ran out on the DS6068 and we had to return it to the manufacturer for reprogramming for a 12-week extension of life.

In effect, although the composite SmartPart device was not tested, we did complete incremental tests of all of the key components comprising the SmartPart system.

2.8 CONCLUSIONS ABOUT PHASE I DEVELOPMENT RESEARCH

Time and the acquisition of required parts in the sequence and configuration desired, not technical impediments appeared as the major obstacles in Phase I. Although the final tasks in the Phase I effort were not completed, we conclude that the SmartPart device as design is feasible, practical and has high applicability to the logistics problems throughout the Department of Defense.

In addition, we expect significant reductions in component size with the next generation of components from Dallas Semiconductor in the 1990 calendar year. Within the research period, several of these components have been compacted in smaller sizes. A dime-sized proximity key device -- in VLSI/VHSIC technology -- should be practical in 2 - 3 years.

Accordingly, a follow-on Phase II of research is contemplated based on the Phase I results, the sponsor's review of this Final Report, and the on-site demonstration of the SmartPart system.

To assure continuity of this research and to help avoid the equipment component scheduling problems witnessed in Phase 1, we are now applying for a State of Ohio "bridge" grant to continue this research in the interim phase between the end of Phase I and the beginning of Phase II. The intermediate objective for this bridge grant is to complete the reduction of the SmartPart design to a printed circuit board (PCB) with sufficient flexibility for a wide range of functional and field tests. That is, we intend to complete the unfinished tasks of this Phase I effort.

-Section 3-
POTENTIAL APPLICATIONS AND COMMERCIALIZATION POTENTIAL OF THE SMARTPART MICRODEVICE

3.1 HARDWARE MAINTENANCE AND SUPPLY FUNCTIONS

The SmartPart design is a subset of the TRACTELL's Logistics Knowledge Based (LKB) series of electronic designs which are directly applicable to discovery-side diagnostics isolate the offending component(s) which, in turn, initiate the supply operations to negate the effects of the problem. The convenient data logging device in the form of the SmartPart, integrally coupled to the relevant component, would lessen these problems.

3.2 HARDWARE SELF-DIAGNOSES

A potent application of the SmartPart is to serve as a link between expert diagnostic systems and hardware components to provide a "self-diagnostic" capability (hardware self-diagnosis is the nature of relevant LKB research performed by TRACTELL under the sponsorship of the National Science Foundation). Current diagnostic expert systems are limited to single applications, and very large knowledge bases are common. As the electronic density of microcircuits increase, the SmartPart will tend to directly support embedded expert system designs by helping to distribute large knowledge bases into more manageable dimensions precisely at the time and place of need -- this is the first stage of hardware self-diagnosis.

3.3 EMBEDDED SENSORS FOR REAL-TIME DIAGNOSTICS

As a commercial product, the proposed SmartPart could dramatically impact maintenance diagnostics and repair for the government and commercial sectors when operated in a semi-autonomous mode interlinked to selected elements of the built-in-test circuitry. The proposed extension to the SmartPart concept, with links to on-component microsensors, fulfills this need and even goes further -- the SmartPart can be accessed without disturbing the host component.

3.4 BIOTECHNOLOGY

In the medical arena, there are many instances of electronic devices implanted in human and other animals. Heart pacemakers; transducers, organ monitoring devices, automatic drug dispensing, specialized sensors as for brain examination, bio-telelemetry devices for animals, etc., are becoming quite common. At present, many implanted devices have to be removed to alter or adjust their function, or a heart pacemaker may not respond to the degree of activity of the implantee. In biomedical research, the mapping of muscle signals in animals is a laborious process, confining the subject to immobility for indefinite periods.

Combining such technologies with the remotely-alterable features of the SmartPart memory would evolve a new level of automated, multi-functional biosensing devices. In such applications, alternate communication modes such as ultrasonics will be needed instead of the RF frequencies as proposed herein.

3.5 SECURITY SYSTEMS AND/OR ELECTRONIC LOCKS

Software locks to protect proprietary or operating system software are well known. However, the SmartPart may offer the a low-cost capability of a software-activated lock for purposes in which ordinary locks are used (doors, windows, etc.).

Of particular interest may be air freight carriers and airport/airline security systems, wherein packages, luggage and carry-on baggage could be electronically imprinted with routing and destination information. Of greater significance, the Smartpart could be imprinted in real-time with information about the individual checking the luggage through the same computer-based system used for ticketing - providing a uniquely powerful counter-terrorist capability.

3.6 COMPUTER-AIDED MANUFACTURING AND ROBOTICS

The SmartPart has applications in computer integrated manufacturing and assembly using robots. For example, sensing elements, using data and models stored on a detachable SmartPart, could signal the initiation of "partial" diagnostics and/or quality control steps to be performed at each assembly stage. Faulty units would never complete the assembly process.

3.7 ANTI-COUNTERFEITING OF CRITICAL DEFENSE COMPONENTS

The SmartPart can be used as an anti-counterfeiting for critical safety-related components in military hardware, such as aircraft, tanks, ships, spacecraft and missiles. By embedding the SmartPart microchip within the native materials of the component during manufacture, unique read-only codes could used, changed, and reverified. Such data could be passively stored for up to ten years and reused many times throughout the life cycle of the host item.

3.8 COMMERCIALIZATION POTENTIAL FOR SMARTPART

For future commercialization of the SmartPart device, two potential sources of Phase III interaction and/or funding are being explored. One is Texas Instruments and the other is Harris, Corporation, both with extensive experience in the VLSI/VHSIC arena. In Phase III, the prime event will be to take the SmartPart design to the VLSI level.

As a business strategy, the adaptation of the SmartPart to multiple applications, first in the maintenance arena, and then others, will be maximized. Two key potential applications of the SmartPart device within the Defense Department are currently being explored.

Sales of the SmartPart will be offered to manufacturers of high- value, reparable items in both government and commercial areas. It is expected that revenues from the software support of the SmartPart product will triple the revenue from sales of the hardware device.

BIBLIOGRAPHY AND REFERENCES

1. Allman, William F., Designing Computers That Think the Way We Do, Technology Review, May/June 1987, p 59.

2. Altman, W. P., et. al., Optical Storage for High Performance Applications in the Late 1980s and Beyond, RCA Engineer, Vol 31- 1, Jan/Feb, 1986.

3. Army Research Institute,, Adaptive Computerized Training System (ACTS), Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, April 1979.

4. Awad, Elias M., Systems Analysis and Design, Richard D. Irwin, Inc, Homewood, IL, 1985.

5. Barney, George C., Intelligent Instrumentation, Prentice Hall International, Englewood Cliffs, NJ, 1983.

6. Bruynooghe, M.,, The Memory Management of Prolog Implementations, Logic Programming, Academic Press, New York, 1982, p 83.

7. Carg, S. K., et. al., The Psychology of Human Computer Interaction, Lawrence Erlbaum Associates, Hillsdale, NJ, 1983.

8. Cole, Bernard C., The Changing Face of Nonvolatile Memories, Electronics, July 9, 1987, pp 61 - 68.

9. Cole, Bernard C., Ferment in Microcontrollers: New Offerings, New Players Stir Up the Competition, Electronics, October 1, 1987.

10. Dash, P. K.; Panda, D. K., Software Technique for a Micro computer-based Digital Instrumentation Scheme Using Functional Expansion, Microprocessors and Microsystems, Vol 9, No 5, June 1985, pp 218 - 226.

11. Davis, R, and Shrobe, H., Representing Structure and Behavior of Digital Hardware, MIT Industrial Liaison Program Report 4-57-84, 1985.

12. DeJong, Ken, On Applying AI to Maintenance and Troubleshoot ing, DTIC AD-P003-915, Alexandria, VA, 1984.

13. Dean, Jeffrey S.,, Advanced Tools for Software Maintenance, Advanced Information and Decision Systems, Mountain View, CA, Dec 1982.

14. Derrick, J. F., Aviation Maintenance Computerized Management Information Systems: Perspective for the Future, Naval Postgraduate School, Monterey, CA, June 1984.

15. Donaldson, P. E. K., Frequency-hopping in RF Energy-transfer Links, Electronics & Wireless World, August 1986, p 24.

16. Ferguson, G. R., Aircraft Maintenance Expert Systems, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, Nov 1983

17. Freeman, P; Wasserman, A., Tutorial on Software Design Techniques, IEEE Computer Society, Washington, DC, 1980.

18. Gevarter, William B., An Overview of Artificial Intelligence and Robotics, NASA Technical Memorandum 85836, NASA, June 1983.

19. Greenfield, Joseph D., Microprocessor Handbook, John Wiley & Sons, New York, 1985.

20. Hirsh, P., et. al., Interfaces for Knowledge-based Builder's and Application-specific Procedures, IBM Journal of Research and Development, No 30, 1986, p 29.

21. Hudlicka, E; Lesser, V., Design of a Knowledge-based Fault Detection and Diagnosis System, Massachusetts University, Amherst, MA, March 1984.

22. IEEE Computer Society, Hardware Test Technology, October 1979.

23. Jeffreys, Dennis C., Reliability and Security of Smart Cards - Laboratory and Field Results, IEEE Conference on Consumer Electronics, June 1986.

24. Knerr, B. W., et. al., Computer-based Simulations for Maintenance Training, Army Research Inst. for the Behavioral and Social Sciences, Alexandria, VA, Dec 1979.

25. Latamore, Berton G., Smart Cards Get Smarter, High Technology Business, September 1985, p 35.

26. McCaffrey, Martin J., Implementing an Expert System for Aircraft Maintenance Discrepancy Scheduling, Naval Post graduate School, Monterey, CA, Sep 1985.

27. McPherson, Joseph H., Bringing Innovations to Market, SRI International, Report No. 704, February, 1987.

28. Neukomm, P. A., Passive Wireless Actuator Control and Sensor Signal Transmission, Sensors and Actuators, A21-A23, Elsevier Sequoia, Zurich, 1990.

29. Nolan, J. G., et. al., A Radiation Powered Single Chip EEPROM ID Code Transceiver, Custom Integrated Circuits Conference, San Jose, CA, May 1987

30. Noratam, Matt, et. al., Choose Ada Compiler Carefully for Simulator Software, EDN, August 20, 1987, pp 133-140.

31. Osaki, S.; Ohshimo, H., Reliability/performance Evaluation for a Multisystem with Preventive Maintenance, Microelectronics and Reliability, Vol 25, No 5, 1985, pp 841-847.

32. Parker, D. B., Learning Logic, Center for Computational Research in Economics and Management Science, MIT TR-47, 1985.

33. Pau, L. F., Failure Diagnosis and Performance Monitoring, Marcel Dekker, Inc., New York, 1981.

34. Poon, R. S., et. al., BioTechnology Instrumentation, SRI International, Report No 722, 1985.

35. Talamonti, Luciano, Contactless Read/Write Memory System, Smart Card 2000, North Holland, 1987

36. Tolpen, Laura, et. al.,, Alterable-Memory MCUs Benefit Designers, Computer Technology Review,July, 1987, page 14.

37. Trisno, Y. S., et. al, Optical Pulsed Powered Signal Telemetry System for Sensor Network Application, IEEE TRansaction on Instrumentation and Measurement, Vol 39, No. 1, February, 1990.

38. Widrow, G., and M. E. Hoff, Adaptive Switching Circuits, Institute of Radio Engineers, Western Electronic Show and Convention, Convention Record, Part 4, 1960, pp 96-104.

TECHNICAL DOCUMENTATION AND REFERENCES

39. Advanced Micro Devices, Inc., Bipolar/MOS Memories Data Book, Sunnyvale, CA, 1986.

40. American Radio Relay League, The ARRL 1986 Handbook, 1986.

41. Intel Corporation, Military Handbook, 1987.

42. Motorola, Inc., Linear and Interface Integrated Circuits, 1987.

43. Motorola, Inc., Semiconductor Technical Data: 8-bit Microcomputers, 1986.

44. Motorola, Inc., Telecommunications Device Data, 1985.

45. Motorola, Inc., Semiconductor Technical Data: HCMOS Single-Chip Microcomputer, the MC68HC11A8, 1986.

46. Motorola, Inc., M68HC11 HCMOS Single-Chip Microcomputers, Programmers Reference Guide, 1987.

47. National Semiconductor, Telecommunications Data Book, 1984.

48. Plessy Semiconductors, Radio Telecoms IC Handbook, 1986.

49. Signetics, Microprocessor Data Manual, 1987.

50. Silicon Systems, Data Book for Analog/Digital, Bipolar/CMOS Integrated Circuits, 1987.

52. Thomson Components, Memory Data Book, 1987.